Development of Cantilever Epitaxy to Produce High Quality GaN with Reduced Threading Dislocation Densities

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Motivation—GaN grown on any currently available substrates has an inherent problem of having to overcome a large lattice mismatch with the substrate. As a result typical planar GaN includes anywhere from 10^8 – 10^{10} threading dislocations per square centimeter. Cantilever epitaxy (CE) is a technique developed to produce areas of GaN with a reduced number of vertical threading dislocations (VTDs) over large areas. Low defect materials are required to reduce leakage and breakdown of both electronic and opto-electronic devices.

Accomplishment—This method requires pre-growth processing to create parallel sapphire posts off of which GaN is laterally overgrown. Figure 1 shows a coalesced CE film. CE does not require a dielectric mask, which can cause doping in regrown material. This is particularly important when creating electrical devices such as HEMTs. The lack of a dielectric mask will also allow us to significantly reduce the number of VTDs in AlGaN, which cannot be accomplished with standard overgrowth techniques due to a lack of selectivity on the dielectric mask.

To produce areas of GaN larger than the area grown from a single cantilever post, dislocations have to not only be removed in the overgrown regions, but also have to be removed over the post, and cannot be created when adjacent cantilever wings coalesce. Figure 2 shows a transmission electron micrograph (TEM) of a CE film that has coalesced over a 4 μm trench from a post that was 8 μm wide. The number of VTDs in the laterally grown material is reduced by two orders of magnitude when compared to the amount found in the material directly over the post. In addition, TEM results show that vertical threading dislocations found near the outer 0.5 μm of the sapphire post turn over and run horizontally i.e. parallel to the sapphire substrate. Further study reveals the turning of vertical dislocations, so that they run horizontally, occurs in other lateral overgrowth techniques such as epitaxial lateral overgrowth (ELO) when steps are taken to insure that the crystal grows to a pyramidal structure before lateral overgrowth commences. This phenomenon provides the opportunity to turn all of the VTDs normally found in the growth over a CE sapphire post by growing to a full pyramid before starting the lateral growth. This pyramidal growth followed by lateral growth to coalescence must occur before growth from the bottom of the trench interferes. The material quality will be compromised by not having free hanging cantilevers.

Atomic force microscopy results concur with TEM results in that the number of VTDs in the laterally overgrown cantilever regions is less than 1×10^7. This is over a two order of magnitude reduction in the number of VTDs when compared to a control section of planar growth. In addition, the VTDs over the post are reduced by an order of magnitude. These results indicate that the proper growth conditions will indeed lead to a situation where vertical threading dislocations over the post are being turned to run horizontally.

Significance—Overcoming the difficulties of growing GaN on a substrate with a 14% lattice mismatch is vital to producing reliable, robust electronic and opto-electronic devices. The cantilever epitaxy technique provides an opportunity to do this for a wide range of binary, ternary, and quaternary materials without compromising the electrical characteristics.

Sponsors for various phases of this work include: BES, LDRD

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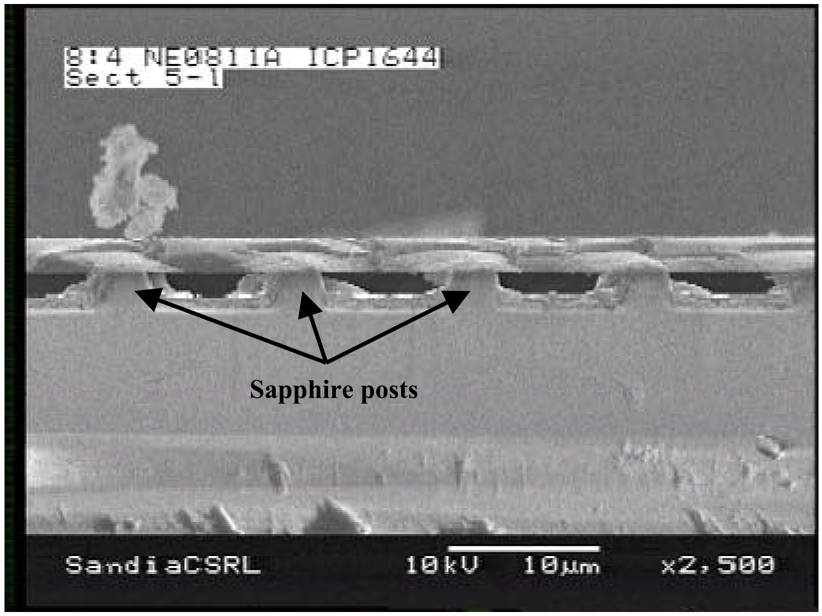

Figure 1. Coalesced cantilever epitaxy film grown off of 4 μm posts over 8 μm trenches.

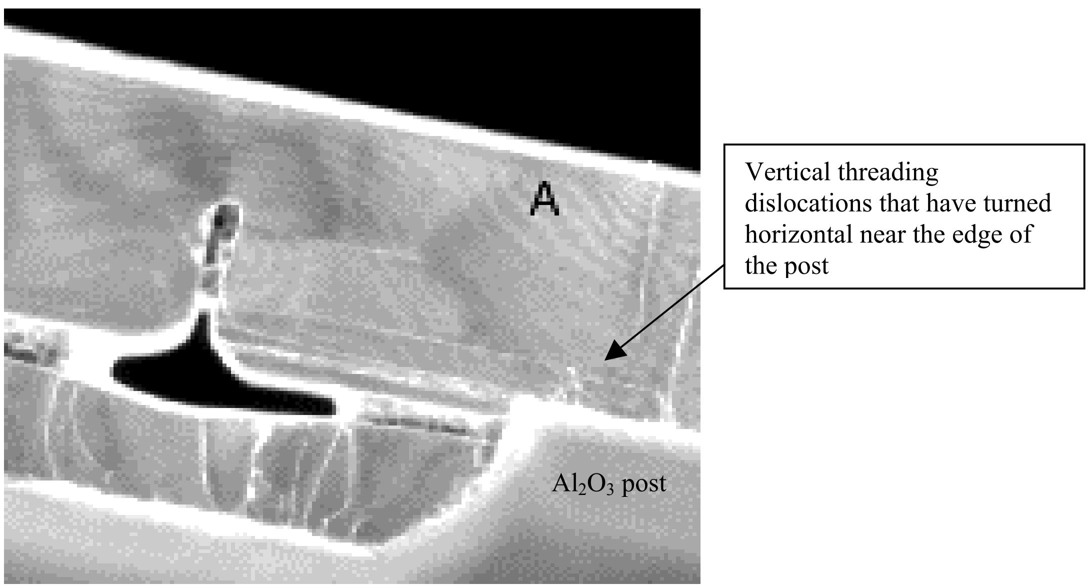

Figure 2. TEM of a CE sample shows no visible threading dislocations to the left of section A and vertical threading dislocations turning horizontally near the edge of the sapphire post.